CHAPTER IX

EFFECTS OF CLOUDS, WIND, SOIL, NITROGEN CONTENT, SUN POSITION AND VIEWING DIRECTIONS ON CORN CANOPY TEMPERATURES

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ABSTRACT

Canopy temperatures measured with infrared thermometers (IRT's) are useful for evaluating crop water stress. To properly evaluate IRT data, however, the effects of various environmental factors should be understood. This experiment done to study the effects of cloud cover, windspeed, level of soil nitrogen, position of the sun in the sky and IRT viewing direction on canopy temperature measurements made in corn (Zea mays L.) with an IRT.

Because canopy temperatures are affected by environmental factors as well as by plant water stress, several cause and effect relationships were identified. Variations in wind speed were found to have an effect on canopy temperatures. Wind gusts cooled the canopy by about 0.5 C. Canopy temperatures rose by about 1 C during calm periods. Decreases in solar radiation at midday due to clouds caused an immediate drop in canopy temperature of about 2.5 C. After the cloud moved to unblock the sun, the canopy returned to the same temperature as before the cloud blockage within about one minute.

When soil nitrogen was severely limiting an increase in canopy temperature of about 1 C was found as was found as compared to that of plants grown under non-limiting soil nitrogen conditions. That temperature increase did not occur under moderately nitrogen limiting conditions suggests that water stress detection with

crop temperature data will not be masked at the soil nitrogen concentrations found under normal field conditions. It further suggests that infrared thermometry can be used to detect nitrogen stress only under severely nitrogen limited conditions.

Under well-watered conditions, only very small canopy temperature differences were observed when the instrument was aimed north or south. When soil water became limiting, however, the temperature of the corn with a southern exposure (observer facing north) was 1 to 2 C warmer than that of the plants with a northern exposure.

In north-south oriented rows, canopy temperatures measured on the east side of the row were as much as 0.8 C warmer than those measured on the west side of the row until about 1000 hrs solar time. This was attributed to differential heating of the canopy caused by the position of the sun at relatively low angles in the eastern part of the sky.

INTRODUCTION

Canopy temperatures have been used by researchers to evaluate plant water stress (Gardner, 1980; Ehrler et al., 1978a, b) and to schedule irrigation (Clawson, 1980 and Chapter VII). Canopy temperature is dependent, not only on plant water stress, but also on various environmental factors. A number of models have been developed to explain leaf temperature dependence on energy exchange (e.g. Gates, 1964; Linacre, 1964; Wolpert, 1962; Edling et al., 1971; Norman, 1979). These models are based on energy balance considerations that involve conservation of mass and energy. These processes depend on physical and physiological

functions, where heat is gained by the plant from solar radiation and lost by convection, radiation and evaporation. Theory thus predicts a dependence of leaf temperature on radiation, wind speed and transpiration. Under constant meteorological conditions, stomatal closure in response to water stress will cause the leaf temperature to rise because of reduced transpirational cooling (Hsaio, 1973). The ways in which plant canopy temperature responds to different environmental conditions must be known before canopy temperature data can be properly interpreted.

Plant temperature responds to variations in cloud cover. Early reseachers detected as much as 7 C difference between shaded and unshaded plants (Clum, 1926). Miller and Saunders (1923) found that leaf temperature differences between turgid and wilted leaves were not as great under heavy cloud cover as they were in full sunlight. Temperature differences as great as 8 C for tomato (Lycopersicon esculentum) leaves under sunny and cloudy conditions were reported by Waggoner and Shaw (1952). Stone et al. (1975) reported sorghum (Sorghum bicolor L. Moench) canopy temperature fluctuations of 3 C during a three minute time span as incoming shortwave radiation fluctuated between 350 and 1000 Wm^{-2}. Gardner (1980) found that cloud passage over stressed and non-stressed corn (Zea mays L.) caused canopy temperatures to decrease by 5.2 and 3.6 C, respectively.

Changes in wind speed can also cause leaf temperature fluctuations. Curtis (1936) found leaf temperature changes of 5 C in response to varying wind speeds. Ansari and Loomis (1959) investigated the cooling effect of wind on pepper (Piper nigrum) leaves in full sunlight. They found that a 2.2 m sec^{-1} wind

cooled leaves by about half as much as did shading the leaves.

In addition to radiative flux density variations, the position of the sun in the sky as well as row orientation can affect the temperature of crop canopies measured with infrared thermometers (IRT). Gates and Tantraporn (1952) showed that in the IR wave-lengths, reflectivity is slightly specular. However, this effect is probably of little consequence to infrared thermometry due to the low ratio of reflected to emitted radiation in the thermal IR wavelengths. Fuchs et al. (1967) found that IRT measured canopy temperatures of alfalfa were unaffected by either solar elevation or azimuth. The viewing angle employed with the IRT also appeared to have little effect except at extremely large or small angles. At intermediate viewing angles, canopy temperatures fluctuated by no more than about 0.3 C. Soybean canopy temperatures, on the other hand, were affected by row orientation, azimuthal and elevation angle. This effect was attributed to uneven heating of the soybean row.

Reports of experiments detailing the dependence of canopy temperature on nutrient stress are not found in the literature. The study reported here was designed to 1) determine the magnitude of canopy temperature fluctuations caused by wind and cloud cover, 2) determine whether canopy temperature is affected by a shortage of available nitrogen and 3) ascertain the dependence of canopy temperature on the sun's position in the sky and on the direction that the IRT is aimed.

METHODS AND MATERIALS

This study was conducted in the solid set irrigation area (Fig. 1) at the Sandhills Agricultural Laboratory (41° 37' N,

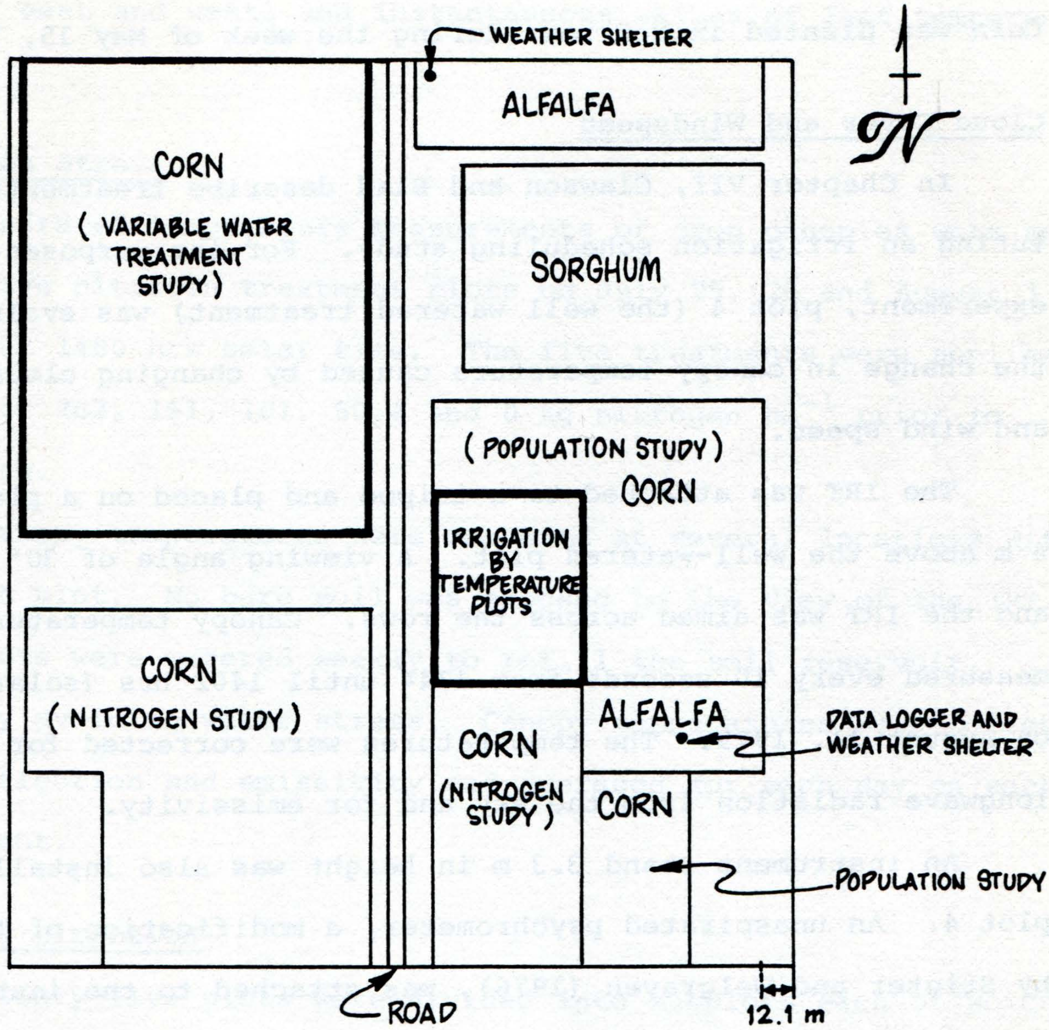

Fig. 1. Experimental plots at the Sandhills Agricultural Laboratory. The plots used in this study are outlined by the dark borders.

100° 50' W, 975 m above m.s.l.). Plot size was 28.3 m E-W by 56.6 m N-S. Each plot was irrigated with sprinklers about 2 m above the ground and spaced 18.9 m apart N-S by 29.3 m E-W. Corn was planted in N-S rows during the week of May 15, 1979.

Cloud Cover and Windspeed

In Chapter VII, Clawson and Blad describe treatments constituting an irrigation scheduling study. For the purposes of this experiment, plot 4 (the well watered treatment) was evaluated for the change in canopy temperature caused by changing cloud cover and wind speed.

The IRT was attached to a tripod and placed on a platform 4 m above the well-watered plot. A viewing angle of 30° was used and the IRT was aimed across the rows. Canopy temperatures were measured every 10 seconds from 1344 until 1402 hrs (solar time) on August 11, 1979. The temperatures were corrected for reflected longwave radiation from the sky and for emissivity.

An instrument stand 3.3 m in height was also installed in plot 4. An unaspirated psychrometer, a modification of the design by Stigter and Welgraven (1976), was attached to the instrument stand at the top of the canopy. Crop height was approximately 2.3 m. Evanohm-constantan thermocouples were attached to the abaxial leaf surface of fully sunlit leaves at the top of canopy near the psychrometer. Five thermocouples were wired in parallel to insure spatial averaging of leaf temperature.

Wind speed and direction were monitored at a weather station at a height of 2 m in the nearby alfalfa plots (Fig. 1). Data were recorded on the hour (solar time) with a Campbell Scientific

digital recorder.[1] Input modules provided continuous hourly averages of temperatures from the mini-psychrometer, mean wind run and wind speeds of four integrated vector components (north, south, east and west) and instantaneous values of leaf temperatures.

Nitrogen Stress

Infrared temperature measurements of crop canopies were made over five nitrogen treatment plots on July 25, 26 and August 1 at about 1400 hrs solar time. The five treatments were applications of 202, 151, 101, 50.4 and 0 kg nitrogen ha^{-1} prior to planting.

Canopy temperatures were measured at several locations within each plot. No bare soil was exposed to the view of the IRT. All plots were watered weekly to refill the soil reservoir, thereby avoiding water stress. Canopy temperatures were corrected for reflection and emissivity and averaged for each day on each treatment.

Viewing Direction

Twenty-five plots were divided into subplots each of which had a different population density. Population densities ranged from sparse (26,000 plants ha^{-1}) to dense (64,250 plants ha^{-1}). 54,500 plants ha^{-1} is considered an optimum population for this region of Nebraska. Irrigation levels ranging from none (dryland) to over-irrigation (140% of that required to restore the soil to field capacity) were randomly assigned to each of the twenty-five

[1]Campbell Scientific, Inc., Logan, Utah (Model CR5).

plots (Fig. 2). Details of the plot arrangement and water treatment are given in Chapter VIII.

IRT measurements were made over each plot between 1200 and 1400 hours solar time from July 25 to August 31. Two spot measurement of canopy temperature were made in two of the four population subplots in every plot. The plot number, plot treatment and direction of view of the plots used to delineate the effects of north vs south viewing direction are summarized in Table 1. The reader should keep in mind that when the observer faces north, he is viewing the side of the canopy facing the sun at mid-day.

Canopy temperature measurements were paired according to population density, irrigation treatment and direction of IRT view. Mean square error (mse) was calculated for each of these ten matched temperature measurements. Standard deviation ($\hat{\sigma}$) of each temperature mean was then estimated by:

$$\hat{\sigma} = \sum_{j=1}^{11} \text{mse}/13$$

Canopy temperatures of identical irrigation and population density treatments were then compared with those for the opposing view directions. A test statistic (t) was computed for each of the seven pairs by:

$$t = |\bar{x}_n - \bar{x}_s|/\hat{\sigma}$$

where $\bar{x}_n$ and $\bar{x}_s$ are the canopy temperatures averaged over the period of measurement for plots having identical water and population treatment with north (subscript n) and south (subscript s) view directions, respectively.

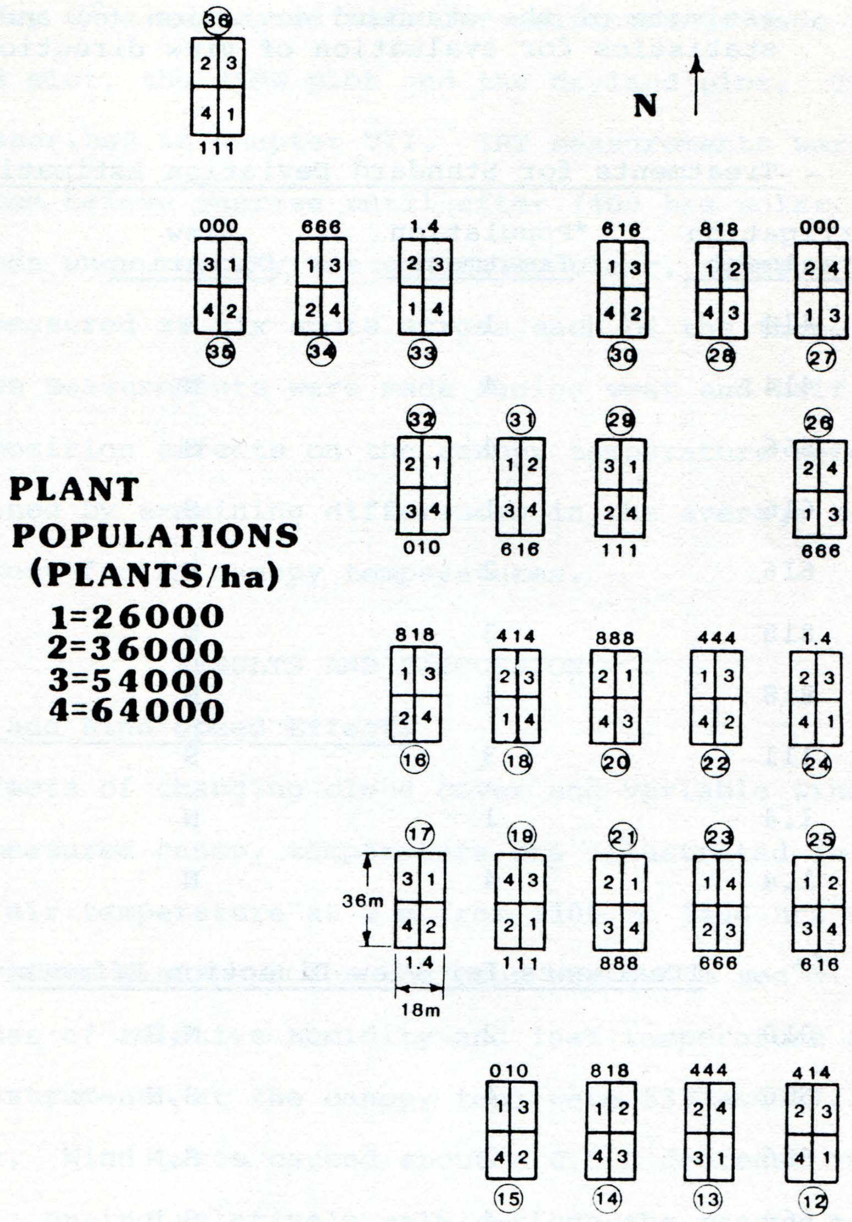

Fig. 2. Map of corn plots used in 1979 viewing direction experiment. Plot numbers are circled, irrigation treatments are in brackets, and numbers in subplots represent plant population levels.

Table 1. Summary of the replicated treatments used to obtain the estimate of the standard deviation ($\hat{\sigma}$) and the test statistics for evaluation of view direction effects.

Treatments for Standard Deviation Estimation

*Irrigation Treatment	*Population Treatment	View Direction	Plot Number
414	1	N	12,18
414	4	N	12,18
666	4	S	23,26
616	1	S	25,31
616	2	S	25,31
818	3	N	14,28
818	4	N	14,16,28
111	3	S	19,29,36
1.4	1	N	24,33
1.4	4	N	24,33

Treatments for View Direction Effects

*Irrigation Treatment	*Population Treatment	View Direction	Plot Number
010	2	N,S	15,32
666	4	S,N	23,34
666	2	S,N	26,34
666	4	S,N	26,34
616	2	S,N	25,30
1.4	1	S,N	17,24
1.4	1	S,N	17,33

*For explanation of these treatments, see Chapter VIII.

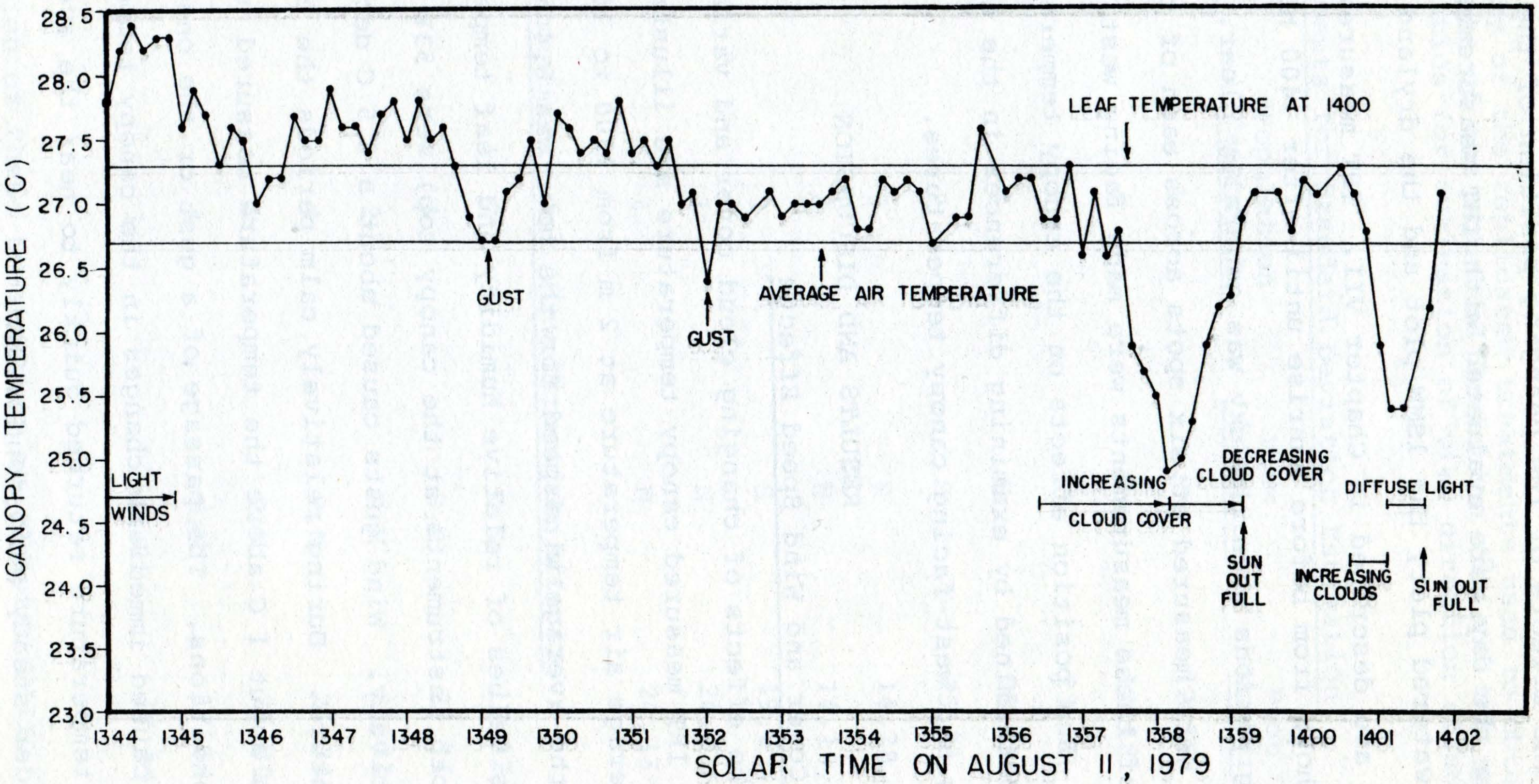

Fig. 3. Canopy temperature fluctuation in response to changing cloud cover and windspeed in a well-watered plot.

Decreases in solar radiation receipts caused by cloud passage resulted in a rapid decrease of about 2.0 to 2.5 C in canopy temperature. After passage of the cloud and return to full sunlight, recovery to the original canopy temperature required about a minute.

If canopy temperatures from one place are to be compared with those from another place they should be obtained under nearly constant solar radiation and windspeed conditions.

Nitrogen Stress Effects

On the three days of observation, the plot which received no nitrogen at planting was consistently 0.6 to 1.0 C warmer than any of the other nitrogen treated plots (Fig. 4). No other nitrogen treatments affected the crop temperature. This suggests that plant temperature becomes elevated only in severely nitrogen stressed plants. It is, therefore, possible that a severe nitrogen problem can interfere with the detection of water stress with an IRT. However, such severe nitrogen problems would probably never occur under normal farm managment, except in small areas where N fertilizer was inadvertently not applied.

These data suggest that nitrogen deficiencies could be monitored by infrared thermometers. This seems to be impractical, however, because the nitrogen stress became apparent to the eye before it became detectable through canopy temperature measurements.

View Direction Effects

The effect of north vs south view direction of the IRT on canopy temperatures was found to be significant (at the 95% level

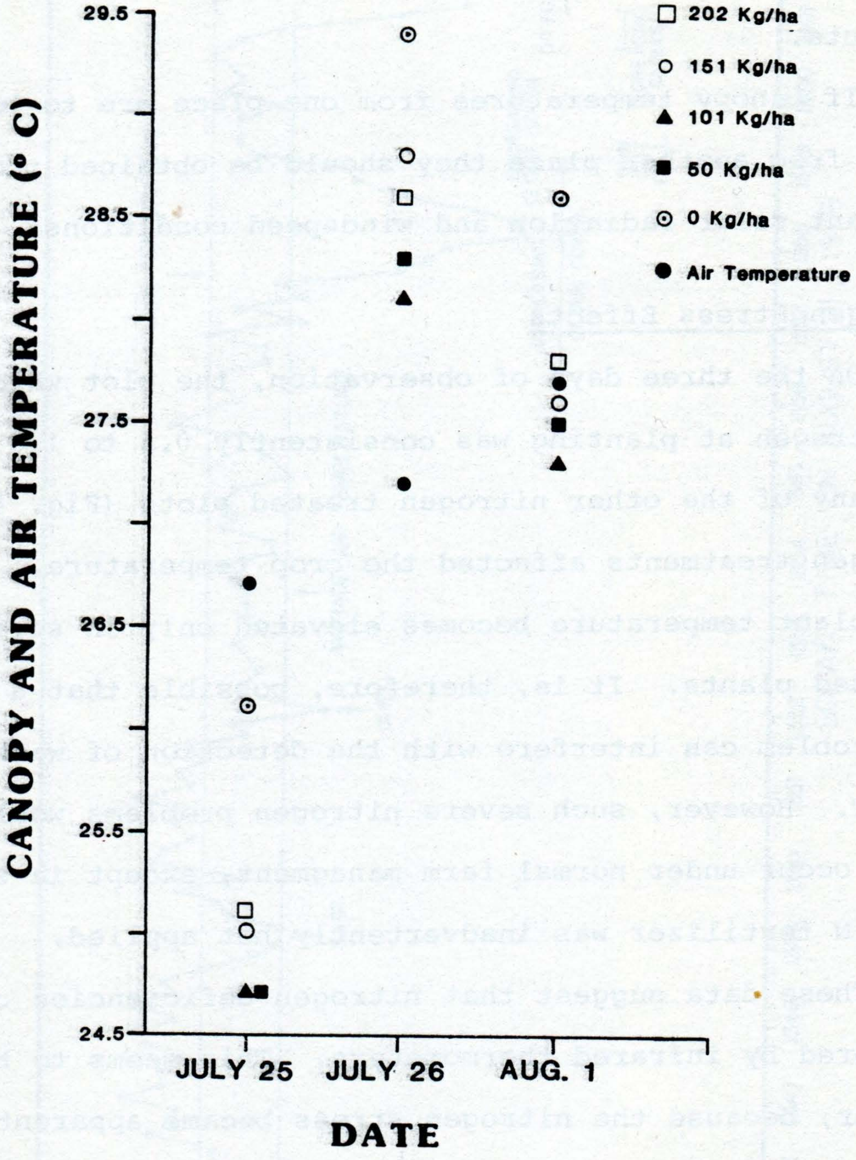

Fig. 4. Average canopy temperatures of plots fertilized at several levels of nitrogen. Readings taken near 1400 hours solar time. Air temperature at 2 m is also listed. Data are for July 25, 26 and August 1, 1979.

of probability) in certain of the plots in which water stress was allowed to develop (Table 2). Under well-watered or at low levels of water stress, there were no significant differences between the canopy temperatures obtained when the instrument was aimed north or south.

Although the effect of viewing direction was found to be significant in certain plots, caution must be exercised in interpreting these data. Plot to plot variation in temperature was observed in plots with identical water and population treatments viewed from the same direction. An example of this variation is given in Fig. 5 for plots 19 and 29. Differences in soil water holding capacities, uniformity of water application and other factors may affect the canopy temperature. Thus, differences in IRT canopy temperatures of identical population densities and water treatments may be due merely to environmental factors and not necessarily to the effects of viewing direction.

Even with these limitations, we still observed that canopy temperatures measured with north facing instruments were warmer than those measured with south facing instruments. This effect is illustrated in Figs. 6 and 7. Test statistics indicate that the canopy temperatures obtained when the IRT was aimed to the north were not significantly warmer than those obtained when aimed to the south in the well-watered (1.4) treatment but they were for the water-stressed (010) treatment.

These results suggest that the effect of view direction on mid-day canopy temperatures measured with an IRT was probably small enough to be neglected when plants were only minimally stressed for water. However, as water became more severely

Table 2. Test statistic of all plots matched by identical water treatment and population density with opposing view direction. Test statistic was calculated from Eq. 2. Significance at the 95% level is indicated by an asterisk.

Plot No.	Irrigation Treatment	Population Treatment	Test Statistic
15 & 32	010	2	3.31*
26 & 34	666	2	3.46*
26 & 34	666	4	1.78
23 & 34	666	4	1.61
25 & 30	616	2	0.24
17 & 33	1.4	1	0.44
17 & 24	1.4	1	1.19

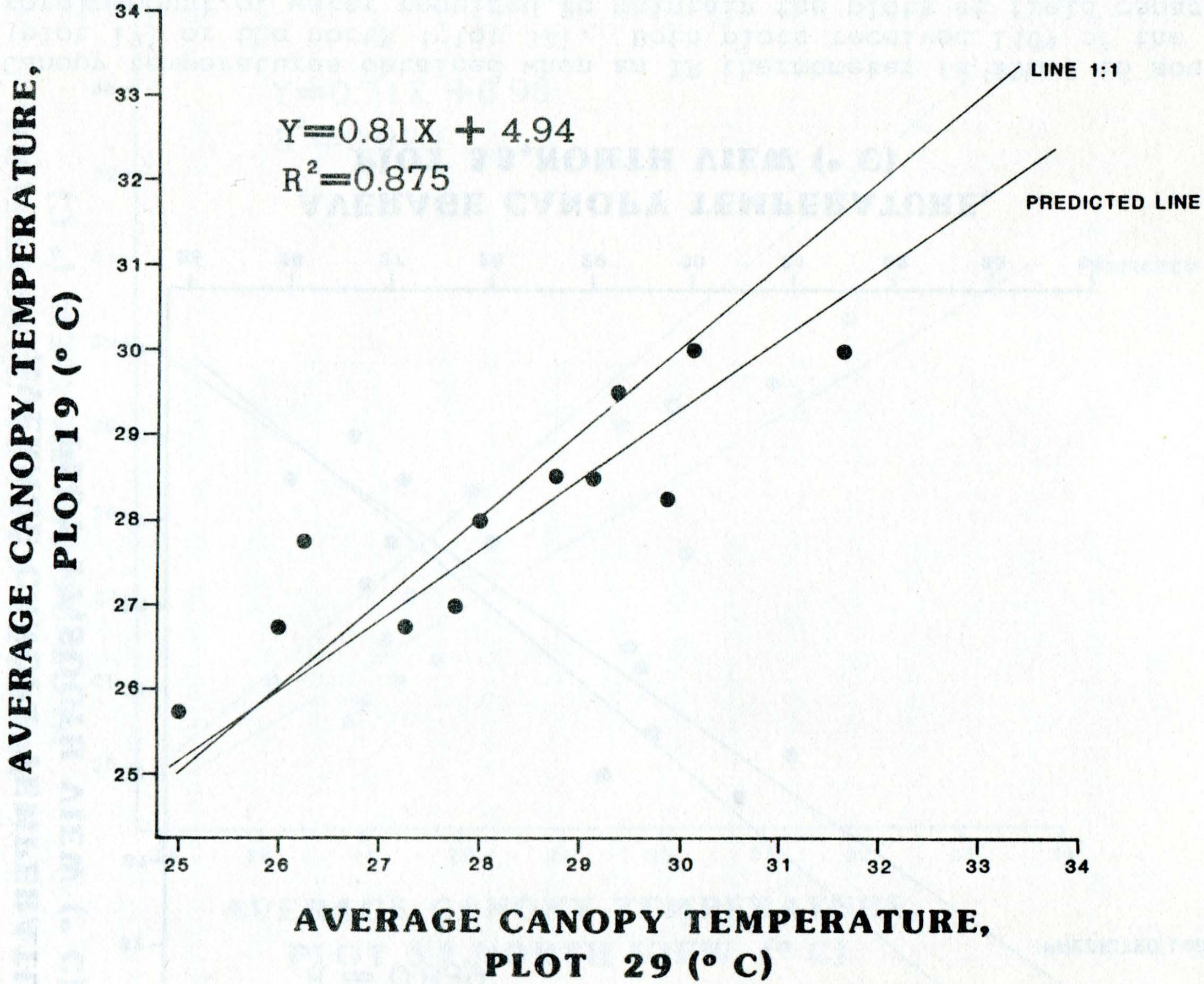

Fig. 5. Canopy temperatures obtained when an IR thermometer is aimed to the south on plots 29 and 19. Both plots received the same irrigation treatment and both had plant populations of 54,000 plants ha^{-1}. Data are for July 25 to August 31, 1979.

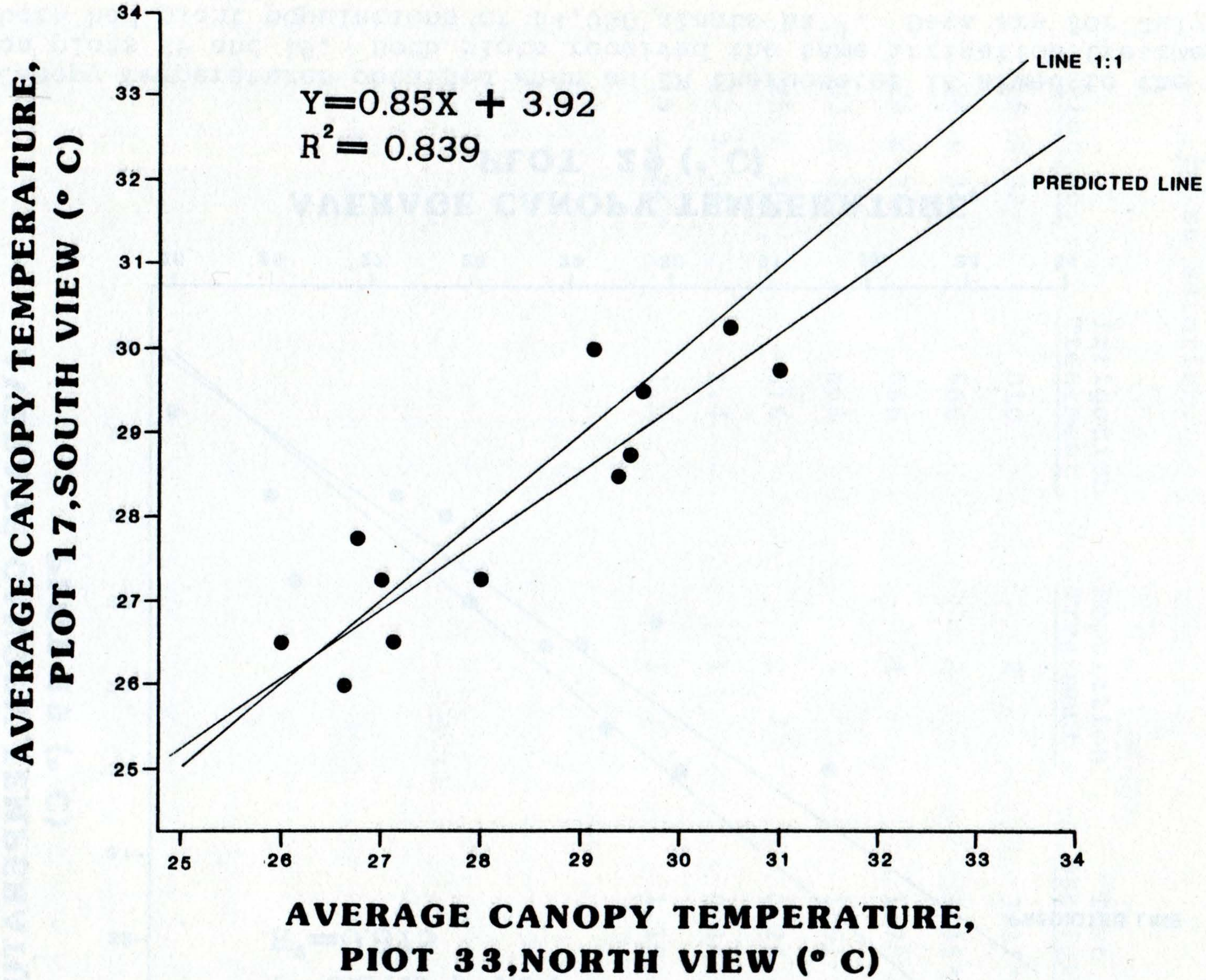

Fig. 6. Canopy temperatures obtained when an IR thermometer is aimed to south (plot 17) or the north (plot 33). Both plots received 140% of the total amount of water required to maintain the plots at field capacity. Plant population in both plots was 6,000 ha^{-1}. Data are for July 25 to August 31, 1979.

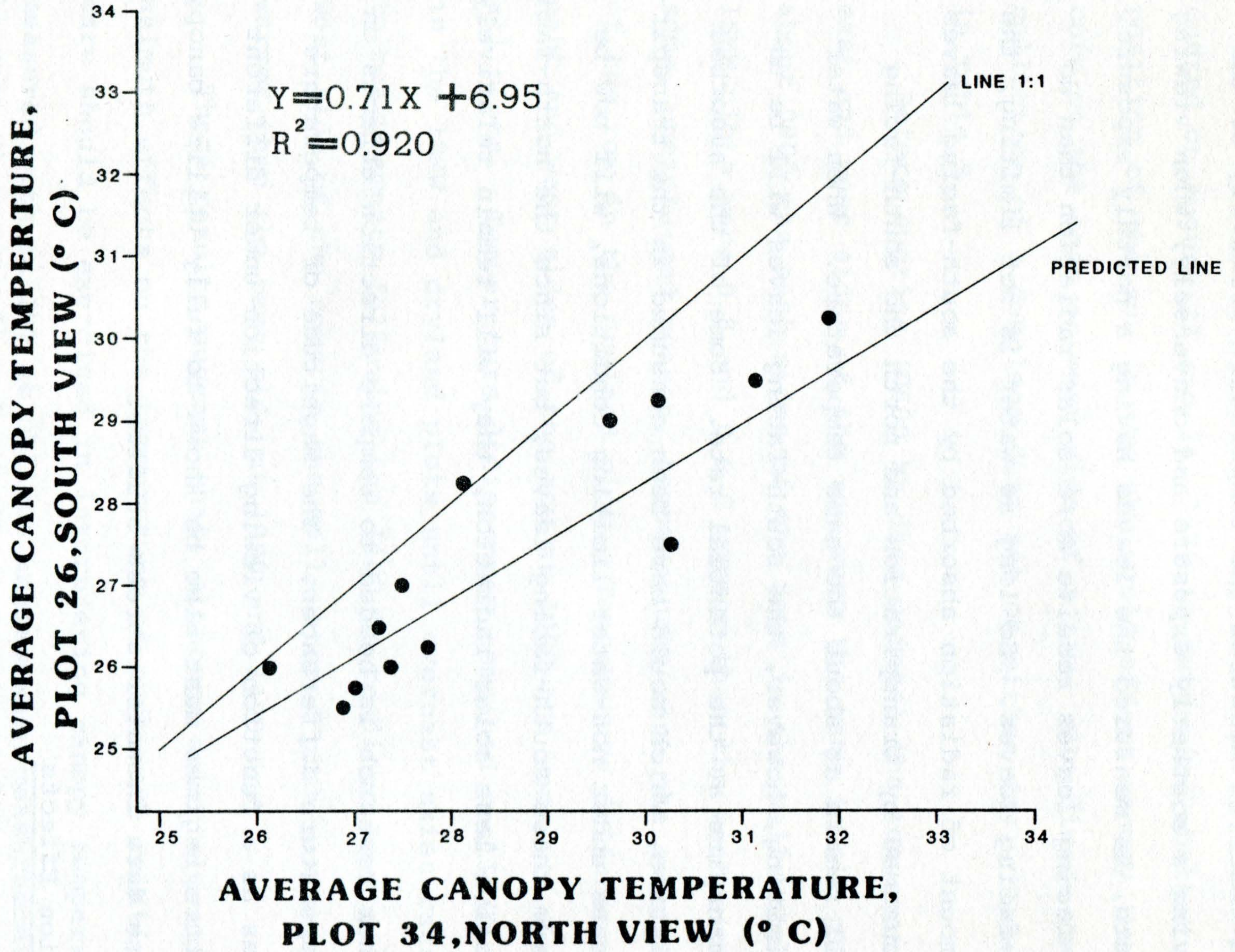

Fig. 7. Canopy temperatures obtained when an IR thermometer is aimed to the south (plot 26) or north (plot 34). Both plots were irrigated to field capacity during the pollination period but received no irrigation during the vegetative or grain-fill periods. Plant population in both plots was 36,000 plants ha^{-1}. Data are from July 25 to August 31, 1979.

limited, then the effect of view direction became important. A possible explanation for this follows: When viewing to the north, the observer measured the temperature primarily of the leaves having a southerly exposure and conversely, when viewing to the south, he measured the leaves having a northly exposure. The south-facing leaves receive more solar radiation than do the north-facing leaves. So long as water is not limiting, the greater amount of radiation absorbed by the south-facing leaves will be consumed by transpiration and north and south-facing leaves will remain at about the same temperature. When water becomes limiting, however, the south-facing leaves will be unable to transpire at the potential rate. Some of the absorbed solar radiation, which would have been consumed in the transpiration process under non-water limiting conditions, will now be used to warm these south-facing leaves, but since the north-facing leaves receive less solar radiation, they will remain relatively cool.

Further research is needed to compare direction effects on canopy temperature differences. The magnitude of temperature differences as a function of viewing direction under different soil moisture regimes must also be known to fully utilize canopy temperature data in water stress studies.

Sun Position Effects

In Chapter VII it was shown that, when the range in corn midday canopy temperatures within a plot exceeded 0.7, the need for irrigation was indicated. Because of the position of the sun in the sky, crop temperature measurements made with an obliquely held

IRT on north-south oriented rows before about 1000 or after about 1400 hrs solar time may show a greater temperature range because of differential heating of one side of a row. A study was conducted on August 23 and 24, 1979 to determine whether or not the position of the sun in the sky would affect canopy temperature of corn on the east or west side of a row. Cloudiness prevented the collection of a complete data set on either day. Results are given in Table 3.

Before sunrise (0600 hr data points) the temperatures on the east and west sides of the row were the same in all plots. By about 0900 the east sides of the rows in the well-watered and the 1SMW plots were 0.8 and 0.6 C warmer than the west sides. For some, unexplained reason, temperatures were the same on both sides of the row in the dryland plot. Temperature differences between east and west sides of the row at 1000 hrs were 0.4 C or less in all plots. Temperature differences remained small (0.4 C or less) in the 1SMW and dryland plots until overcast skies caused an end to measurements following the 1400 hr readings on August 24. The west side of the rows in the well-watered plot was about 0.6 C warmer than the east side at 1300 and 1400 hrs.

These results suggest that, although solar elevation and solar azimuth effects on the temperature of corn were relatively small, care should be exercised in interpreting canopy temperature data measured with an IRT at oblique angles when measurements are made before or after the 1000 to 1400 hr period. For example, the temperature differences caused by solar elevation and azimuthal effects on August 23 at 0900 in the well-watered plot were of sufficient magnitude to suggest that certain plants were under

Table 3. Comparison of canopy temperatures obtained from east and west side of corn rows in the dryland, well-watered and 1SMW plots. Data were obtained on August 23 and 14, 1979. Each temperature is the average of three readings.

		Well-Watered		1SMW		Dryland	
Date	Time	East	West	East	West	East	West
8/23	0600	11.7	11.7	11.9	11.9	12.0	12.0
8/23	0700	15.9	16.0	16.9	16.5	16.2	16.2
8/23	0800	18.6	18.5	19.2	18.8	19.8	19.6
8/23	0900	21.1	20.3	22.0	21.4	22.4	22.3
8/23	1000	23.1	22.7	23.1	22.7	24.1	24.4
8/24	1100	25.5	25.6	25.8	25.5	26.3	26.2
8/24	1200	25.1	25.0	26.0	25.8	27.3	27.2
8/24	1300	26.0	26.6	26.3	26.1	28.5	28.8
8/24	1400	23.8	24.4	24.6	24.3	25.9	26.3

*On August 23 skies were clear until about 1000 hrs. Cloud began building up and interfered with readings after 1000. On August 24 skies were almost clear during the 1100-1400 readings but become overcast before 1500.

very mild water stress but the 1200 to 1400 readings indicated that this was not so.

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